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THE "OLD-FASHIONED" WINTER OF 1917-18¹

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In the United States east of the Rockies the past winter was remarkably cold. Some of the details can be explained, even though the reason for the occurrence can only be surmised. The early appearance of freezing temperatures in the Mississippi Valley heralded a type of weather which, with cold waves of increasing severity, overspread the United States east of the Rockies and then held the country in its icy grip for two months. Finally, a sudden warm spell saved from catastrophe the almost despairing cities of the East. In the autumn, corn was caught unripe; winter wheat did not make proper growth; cotton picking was interrupted early; truck crops and fruit were damaged. In the winter, the already over-burdened railroads were blocked by snow, or their locomotives were barely able to keep up steam in the below-zero gales; while rivers and harbors were locked with ice of unprecedented thickness. Even Nantucket was tied to the mainland by a 15-mile ice bridge. Many industries, without their normal income of supplies and outgo of finished products, were forced into partial shut-downs or complete suspensions of work. People suffered from the severe cold, the lack of fuel threatening serious consequences with each renewed snowstorm or cold wave. Moreover, other parts of the world were also experiencing record-breaking droughts, floods, storms, cold, or heat. What was the cause? Variations in solar energy received by the earth must have been basically responsible. The effects of a more energetic atmospheric circulation are manifested differently in different parts of the earth, especially since snow-covered lands and unusual ocean temperatures are frequently involved in the final results. While the present degree of solar activity lasts, further extremes of weather are not unlikely. But these cannot yet be forecast.

A survey of the winter just passed, however, does bring out some immediate connections of the weather with local water temperatures and snow cover, as well as the general tendency to extremes in terrestrial weather. Before taking up the phenomena of the past winter, let us take a general

¹ General references:

U. S. Weather Bureau Publications:

Daily weather maps of the United States, published at Washington.

Snow and Ice Bulletin, published weekly, December to March.

National Weather and Crop Bulletin, published weekly, April to September, and monthly, October to March.

Climatological Data for the United States by Sections, monthly.

Monthly Weather Review.

Reports of the Associated Press, and special reports in the *New York Evening Post*.

Symons's Meteorol. Mag., London, containing a summary of British weather each month.

view of the following points: (1) how the 11-year sunspot cycle is connected with the earth's weather; (2) how changes in the intensity and position of the "grand centers of action" of the atmosphere produce great regional abnormalities in temperature and rainfall; and (3) how local temperatures where water or snow prevails affect the weather.

THE 11-YEAR SUNSPOT CYCLE

The 11-year sunspot cycle is a cycle in solar activity, during which the sun radiates the most heat when spots are most numerous.² For some reasons, however, the earth in general is colder than when the sun radiates less. At any rate, as we should expect, the atmospheric circulation is most energetic when the sun is sending the most energy. Changes in the strength of the atmospheric circulation necessarily go hand in hand with changes in the steepness of the barometric gradients. In other words, the great high-pressure areas are higher than usual and the low-pressure areas lower than usual in times like the present, when the sun is hotter than usual.³

CHANGES IN THE "GRAND CENTERS OF ACTION" OF THE ATMOSPHERE

Now, let us consider the second point: How do changes in the intensity and position of the "grand centers of action" of the atmosphere produce great regional abnormalities in temperature and rainfall? In consequence of the general circulation of the earth's atmosphere there tend to be belts of high pressure at the horse latitudes—about 30° N. and S.—and troughs of low pressure in subpolar latitudes. The contrasts between the temperatures of the continents and oceans, however, produce the well-known tendency to continental high pressures in winter and low pressures in summer, while there is the reverse tendency over the oceans. In the northern-hemisphere winter, therefore, we have such subpermanent centers as the Iceland and Aleutian "lows" and the North American, Eurasian, Hawaiian, and Azores "highs." These highs control the directions and strengths of the general winds, and in this way they control the weather characters of the different regions. With normal positions and strengths there occurs the normal weather in the different regions, anomalous though this weather may be when compared with the means for the latitude. What temperature departures will be produced by an intensification of these centers of action? The places already too warm for the latitude will become warmer and those too cold will become colder: for instance, western North America should become warmer and eastern North America colder than usual. Rainfall differences will be intensified in much the same way: interior regions usually dry may become very dry with the higher pressure, while peripheral regions usually wet may become extremely wet with the stronger cyclonic activity. Increased circulation had general results of

² C. G. Abbot: *The Sun and the Weather*, *Scientific Monthly*, Vol. 5, 1917, pp. 400-410.

³ H. Arctowski: *Variations in the Distribution of Atmospheric Pressure in North America*, *Bull. Amer. Geogr. Soc.*, Vol. 42, 1910, pp. 270-282.

this sort in North America during the past winter. But with shifts in the positions of the centers of action, wind directions are changed, and with winds from unusual directions the character of the weather will tend to depart from the normal, in general corresponding to the difference between the usual weather brought by the new wind and that by the normal wind. An apparent westward shift of the Eurasian high this winter gave to Europe a continental climate in many respects like that of the interior of North America.

CONTROL OF THE WEATHER BY SURFACE TEMPERATURES

At all times, the diverse temperatures of water, land, and snow surfaces control weather details, which, when long continued, become large features. These surfaces affect not only the temperatures and moisture content of the winds, but also control the paths and strengths of cyclones and anticyclones. Water surfaces, whenever warm relative to the surrounding temperatures, always become centers of cyclonic activity and, therefore, are stormy. Snow surfaces and water surfaces, when relatively cool become, on the other hand, areas of quiet coldness.⁴ Applying such tendencies to the past winter in the United States the weather facts fall naturally into place. On account of the high specific heat and mobility of water, air temperatures in autumn over water tend to remain higher than those over land. When the land is cold, as it was this winter, the contrast may become so strong that unusual storminess results on the border between the cold land and the relatively warm water. The potential energy of the water vapor helps to increase the storm energy over what the mere temperature contrast might produce. The limited maximum temperature of a snow surface, its reflecting qualities, and its very low conductivity favor the excessive cooling of the air. The snow-cover, when once established, will tend to maintain itself in a number of ways. (1) Under these conditions melting and evaporation are slow processes. (2) The prevailing coldness of the air favors the occurrence of snow rather than rain with passing storms. (3) The cold air is dense, and, therefore, favors high pressure, which in turn will aid in the formation of storms on the edge of the snow cover, where a temperature contrast is likely also.

Here is our background for the extraordinary weather of the past winter: (1) a hot sun, therefore a general tendency to strong continental winter anticyclones and ocean cyclones, with corresponding storminess and coolness; (2) for North America a strong winter anticyclone favoring coldness in the east and warmth in the west; (3) where there are strong temperature contrasts, particularly great storminess, but where the contrasts are small, relatively quiet weather.

⁴ See, for instance, H. J. Cox: Influence of the Great Lakes upon Movement of High and Low Pressure Areas, *Proc. 2nd Pan-American Sci. Congr., Washington, Dec. 27, 1915-Jan. 8, 1916*, Section II, Vol. 2, pp. 432-459, Washington, D. C., 1917.

AN UNUSUAL AUTUMN IN THE UNITED STATES

The advance guard of our cold winter appeared on August 8 when a strong winter type of anticyclone, or "high," entered the United States from the Canadian Northwest. Freezing temperatures occurred on the morning of August 9 over a considerable area in the northern Great Plains. Similar dry and clear and, therefore, cold high-pressure areas entered on August 27, September 8, and September 22. The first produced the first killing frosts in most of North Dakota, northern Minnesota, and Wisconsin; the second cold period, September 9 to 14, brought killing frosts east of the Mississippi and north of the 40th parallel. A procession of three more "highs" from the Canadian Northwest entering the United States on October 4, 7, and 11 so reinforced one another that freezing temperatures were flung southward into Texas, southern Mississippi, and eastern North Carolina—far beyond the regions where killing frosts had previously been reported so early in the autumn. The sequel was a snowstorm in the southern part of the Great Lakes region. A similar group entering the country October 18, 20, and 22 pushed the frost line to the Gulf coast and into Florida. There was another Great Lakes snowstorm, with light snowfall south into half of Tennessee. The climax of the wintry autumn came from October 28 to 31, when a tremendous cold wave with unheard-of October temperatures swept out of the northern Rockies and across the plains south to Mexico and east to the Gulf and Middle Atlantic coasts. The temperature at Denver fell to -2° F. and that at Pueblo, Colorado, to -4° F. Again, a Great Lakes snowstorm occurred. The continual cloudiness and unusual storminess, particularly during the last ten days of October in the northeastern quarter of the country, were reflections perhaps of the temperature contrast between the warm lakes and the prevailing cold weather about them. From the Missouri and Mississippi Rivers eastward this October was the coldest on record in most states and the wettest in many. The snowfall was extraordinary for October. Many stations in West Virginia had 15 inches, and central Wisconsin received $17\frac{1}{2}$ inches during the month. More than two feet of snow fell at the higher stations in the Black Hills.

EXTREMES OF WEATHER IN OTHER REGIONS

Unusual weather was not confined to the eastern United States nor to this continent. Over a large part of the United States west of the Rockies October was rainless or almost so and considerably above normal in temperature. Many places had the highest October temperatures on record, e. g. San Francisco, 96° F., Needles, Cal., 112° F. A flood in China in late September and early October is said to have been without parallel in destructiveness of life and property. A typhoon, particularly destructive in Tokyo, reported October 1, seems to have formed at the same time as a similar storm which visited the southeastern United States two days earlier.

In Natal, on October 27-28, four months of abnormal rainfall culminated in a storm yielding more than eight inches in 24 hours and producing disastrous floods. The weather of the British Isles was not unlike that of the northeastern United States: "low mean temperature, and a general excess of rainfall with frequent and unseasonable snowstorms in northern districts."⁵

NOVEMBER WEATHER

The first twenty days of November in the northeastern quarter of the United States stood in marked contrast to the closing decade of October. November was generally quiet and dry throughout the country. Over the northern Great Plains, the warmest November on record was sandwiched in between the coldest known October weather and an extraordinarily cold December. In much of this region November was actually warmer than October, locally in North Dakota the mean for November being more than 4° F. higher than that for October. Whereas at Sheridan, Wyo., a temperature of -12° F. had been recorded in October, the lowest in November was +18°. Farmers were able to resume plowing and, near the Rocky Mountain front, to continue with few interruptions till Christmas. The weather of the British Isles also was mild, the temperature being only very slightly lower than that of October. The south was extremely dry, but the west of Ireland and northwestern Scotland were exceedingly wet. The eastern third of the United States remained below normal in temperature during November, as for many previous months. In the last of November killing frosts occurred generally on the Gulf coast and into central Florida, and in the eastern Great Lakes region a heavy snowstorm was followed by record low temperatures for November, reaching -16° F. at Moira, N. Y.

DECEMBER WEATHER

December continued the weather type of October. A trial cold wave entered the United States from the Canadian Northwest on December 3, and on December 7 a more substantial one entered the northern Great Plains just as a strong cyclone was beginning to operate over the southern Great Plains. Considerable snow fell over the Plains south to Oklahoma and central Arkansas. Then, as the storm advanced eastward and gathered energy from the moisture of the Atlantic and the Great Lakes, the snowfall became heavier over the Ohio Valley, where on a strip less than 50 miles wide one to three feet of snow fell; and in the lee of Lake Ontario parts of western New York were buried under two feet of snow.⁶ This snow cover with later additions helped to maintain the below-zero weather in the Middle West until December 17. The lowest temperatures in this cold spell, except west of Lake Michigan, occurred in the immediate

⁵ *Symons's Meteorol. Mag.*, Vol. 52, 1917, p. 119.

⁶ See the maps of daily snowfall in the cyclone of February 20-23, 1912, which took about the same route, *Monthly Weather Rev.*, Vol. 42, 1914, pp. 325-330.

vicinity of the Ohio River on December 9, 10, and 11, before the deep snow had increased in conductivity by becoming packed. The extremes were -25° F. in western Tennessee, -20° in western Kentucky, -30° in southern Indiana, and -31° in southern Ohio. In western Tennessee the four stations with minima of -20° or lower were in a narrow belt immediately southeast of the heaviest snow belt but still within the region with six inches or more of snow on the ground. Cairo, near the windward edge of the snowy belt, had a minimum of -7° ; while Nashville, with but three inches of snow and lying a short distance southeast of the cold strip, reported zero as the lowest.

NEW LOW RECORDS OF TEMPERATURE

Owing to a thaw in the Middle West from December 18 to 24, as some of the northern cyclones were able to cross to the Great Lakes and eastward, the snow line temporarily receded to the Great Lakes region and the Appalachians, only to return as on December 27 the greatest anticyclone of the winter began slowly to settle over the country. In the Yukon probably a new minimum temperature for the North American continent (-86° F.) was reported at the mouth of the Pelly River. In the Appalachian and Atlantic coast region, where the snow still remained on the ground, this cold wave established new low December records for most states, and at many stations (New York City and Boston among them) the weather was the coldest ever recorded since 1870 at least. Except for Kentucky and Maryland the following minima established new state records for December, during the past twenty-five to thirty years at least: West Virginia, -37° ; Maryland and Tennessee, -32° ; New Jersey, -29° ; Virginia, -27° ; North Carolina and Kentucky, -21° ; South Carolina, -6° ; Michigan, -38° ; South Dakota, -45° ; Iowa, -40° ; and in New England a range from -45° in Maine to -16° in Rhode Island.

The month as a whole was either the coldest or the warmest December on record in about two-thirds of the United States. The New Jersey section summary considers that it will "serve to refresh the memory of the 'oldest inhabitant' regarding an 'old-fashioned winter.'" In Ohio, a 64-year record fails to show a colder December. The "ice conditions on the Ohio River at Cairo exceeded in severity anything in the memory of the oldest inhabitant" (Illinois section summary). In marked contrast, all of the United States west of a line fifty to two hundred miles east of the Rocky Mountain front was warm. In southern Idaho the mean for the month was locally 12° above normal: it was so warm that winter grains, alfalfa, clover, and grasses made considerable growth. And yet only three hundred to four hundred miles to the northeast Havre, Montana, was 13° below normal. The immediate cause of this sharp contrast was the prevalence of southwest winds across the mountains and of northeast winds on the Plains. For most states December was a dry month, for some the

driest December on record. From Texas to Nevada and California practically no rain or snow fell. In Texas, it was the driest of sixteen consecutive dry months. On the other hand, western Washington, western Oregon, northern Idaho, and northwestern Montana were extremely wet. One station in Washington, Cedar Lake, reported 46.80 inches of rain during the month.

JANUARY WEATHER

Like December, January was cold and snowy but dry in the central and eastern United States. The presence of the extensive and deep snow cover seems to have been primarily responsible for this cold weather, in spite of subnormal pressures throughout the eastern half of the country. In fact, there seems to be little occasion to consider the weather of this month as being under any control beyond the immediate effects of the land, snow, and water temperatures and moisture supply. As in the region east of the Mississippi in December, the greatest departures of January temperature from the normal occurred in those areas with the greatest depth of snow on the ground, if the upper Great Lakes region and the northern Appalachians, which are normally snow-covered, are left out of consideration. As expected, a series of intense cyclones which followed in a general way the southern edge of the snow-covered area produced snowstorm after snowstorm for some distance southwest and south of the Great Lakes and on the Middle Atlantic Coast. Many cyclones entered the warm, moist Great Lakes region and produced almost daily snows on the lake shores. In the Middle West the blizzard of January 12 will long be memorable as "that cold Saturday" for its southwest gale with driving snow at -20° F. On the main line of the Illinois Central Railroad in central Illinois, it was reported that there was no traffic to or from Chicago for forty-eight hours. In the south, snow fell into the Gulf of Mexico (the snow at New Orleans being the first in thirteen years), and in Texas south almost to Brownsville. The very intense cyclone responsible crossed the central United States along the southern edge of the snow cover and then moved northward to the favorable temperature and moisture environment of the Great Lakes. The cold air was supplied by an intense anticyclone in Alberta on January 10. The heaviest snowfall during the month occurred near the southern end of Lake Michigan, notably at Milwaukee and Chicago, where the falls of 52.6 and 42.5 inches respectively exceeded the record for any month and the normal amount for a whole winter. There was no rain at Chicago during the month. This heavy snow on the southwest border of Lake Michigan was brought principally by cyclones passing on the south. It was snowier here than elsewhere south of the Great Lakes because the northeast snow-bearing winds had over Lake Michigan the greatest unobstructed sweep over a water surface. Topographic influences and more intense cyclonic activity produced another belt of extraordinary snowfall,

locally four feet, on the Ozark Plateau and over the Ohio River. The Middle Atlantic coast continued snowy because of the numerous cyclones passing over or up the coast, between the Gulf Stream and the cold, snow-covered land. With so much snow on the ground it is not surprising that in the Ohio Valley and eastward the temperature rarely rose above freezing and occasionally fell below zero. Extremely cold weather prevailed in New England through the month. The average temperature for the section, 13.2° , was the lowest for any month since 1888 at least. "In a record extending back to 1836, at Amherst, Mass., the average temperature of the present month was lower than that of any month heretofore. The greater portion of the precipitation was snow, which, in the interior of the northern portion of the section, accumulated to between three and five feet in depth."⁷ Much snow, cold, relative dryness: these are interrelated elements. The Ohio section report states: "It is safe to say it (January) satisfied to the last degree the longings of the most fastidious for an 'old-fashioned winter.'"

FEBRUARY COLD WAVE

A final severe cold wave which occurred early in February in the northeastern United States was the coldest of the winter at many places. Even at Provincetown and Nantucket the temperatures fell to -6° F. The ice in Long Island Sound was said to have been the heaviest in more than fifty years. It was reported that for the first time known the main channel used by Boston to New York ships between Nantucket and Cape Cod was closed by a solid bridge of ice. Some tugs were icebound for twenty days.

THE WINTER IN EUROPE AND ELSEWHERE

European weather was not unlike that experienced in the eastern United States. The British Isles in December had low mean temperatures and deficient rainfall. London had the coldest December since 1890. The winter weather continued with severity till the middle of January, after which the weather was remarkably mild. The cyclone which brought the first general snowstorm in the United States, December 7-10, seems to be the same which with a northwest gale, snow, and extreme cold unroofed houses in Queenstown on December 15 and then tied up the traffic in and about Paris on December 16. On January 2, a Paris report mentioned another heavy fall in central and eastern France which snowbound the region, St. Etienne having three feet. The temperature at Lyons was at zero (F.)—an almost unheard-of cold for that region. Paris was experiencing less snowy and somewhat milder weather. A January 10 report from Stockholm told of unprecedented temperatures in northern Sweden, a minimum of -70.6° F. occurring at Asele. Early in February Madrid reported one of the most severe winters in years, following an autumn with

⁷ New England section of the "Climatological Data," January, 1918.

no rain. "The snowfall in Asturias has blocked up the Puerto Pajarez, and the trains remain for days in the snow-drifts, unable to proceed." In Madrid the government departments had no coal, Seville had no gas, Valencia no wood. From the southern hemisphere came the reports that late in January and again early in March tropical cyclones produced great damage in Queensland. In the middle of February, Natal and Johannesburg were again flooded by rains, which at some places amounted to nine inches or more in twenty-four hours.

With similar cold weather in North America and in Europe, it seems reasonable to point to a world-wide connection—one possibly controlled by unusual conditions on the sun. Proof must await the reduction of the solar radiation values for this period. The weather proved characteristic of a winter period under the influence of an active sun.

SUDDEN WARMTH IN THE EAST

In the eastern United States, the weather moderated immediately after the early February cold wave. The temperature at Cleveland, for instance, rose from -12° to $+40^{\circ}$ F. in twenty-four hours. From February 6 to 14, the temperature in the middle Mississippi Valley and the middle of the northern Plains averaged 15° to 20° above normal. The snow cover disappeared with almost unbelievable rapidity north nearly to the Great Lakes and along the Atlantic coast to New England. Although there were other cold waves, this general moderation of the weather marked the end of the extraordinarily cold and snowy winter which had dominated the central and eastern United States since early December. If it had not been for the snow cover, it seems as if the change would have occurred ten days earlier, when the first "lows" began to cross the northern United States first to the Great Lakes and then to the Atlantic. Earlier in the month three such storms had gone to pieces over the northern Plains and re-formed in the warmer South.

SUDDEN CHANGE ON THE PACIFIC COAST

There was a change in the weather type on the southern Pacific coast at the same time with that in the eastern United States. During the fall and winter, Utah, Arizona, Nevada, California, and some of the surrounding regions were experiencing an almost unbroken drought and unusually warm weather. A severe shortage of water for irrigation was threatened, for there was scarcely any snow on the mountains. For instance, the snow on the ground at Summit, Cal., at the end of January was but two inches as compared with the usual six feet at this time of year. But at the same time that the heat was turned on with such unexpected suddenness in the East, the water was turned on in the Southwest. Central California's first heavy rainstorm of the winter came from February 4 to 6, and heavy rains commenced in southern California on February 17. Until these heavy

rains occurred, San Francisco had had less than 20 per cent of the normal winter rainfall and Los Angeles less than 10 per cent. All talk of a water shortage was silenced by a heavy fall of snow on the Sierras, which at Summit amounted to about ten feet for the month. Aside from any direct solar effects the relations of water to air temperatures here may have been sufficient to change the weather type. For a few months the winds on the Washington and Oregon coast had been rather strong from the southwest, especially in December. If these winds extended farther south offshore it seems reasonable that the warm water driven north should after a time have favored cyclonic action, especially since the lands had cooled to temperatures probably below those of the water.

Another aspect of water temperatures is manifest in the spring following such a severe winter. For example, in the northeastern United States the heavy snow on the ground in the northern highlands and the coldness of the Great Lakes and of the coastal waters north of Hatteras continued to favor dry weather even into April. Similar conditions have been observed in the Baltic region after a cold winter.⁸ Does this explain the dry spring weather of the western battle front this year?

SUMMARY

Such were the characteristics of our remarkable winter. The causal sequence of events seems to have been as follows: In the first cycle: great continental anticyclone—clear, dry air—strong radiation—cold—snow with the next passing cyclone. The second cycle is more complicated and longer: another anticyclone—intense cooling of the snow surface and overlying air—extreme cold—dense lower air—maintenance or increase of high pressure—marked temperature contrast between snow cover and the bare land or open water—strong cyclonic action with more snow near the border of the snow cover. And then another intense anticyclone begins a third cycle like the second. Finally, long-continued southerly winds eliminate most of the snow cover, and then the warmth of the early spring sun shining through the dry air prevents the recurrence of another winter cycle. The anticyclones thus initiate a long train of weather reactions. Was each of these anticyclones produced by a sharp increase in the solar energy received by the earth? A periodic recurrence noticeable in the highest pressures observed in the region embraced by the United States weather map is suggestive of such a connection.⁹ The past “old-fashioned” winter, then, may have been caused by a sun hotter than usual which brought on self-perpetuating cold waves and droughts.

⁸ H. H. Hildebrandsson: Quelques recherches sur les centres d'action de l'atmosphère, *Kungl. Svenska Vetenskapsakad. Handl.*, Vol. 51, 1914, No. 8.

⁹ H. H. Clayton: Effect of Short-Period Variation of Solar Radiation on the Earth's Atmosphere, *Smithsonian Misc. Colls.*, Vol. 68, No. 3, May, 1917, p. 18 (reviewed in *Geogr. Rev.*, Vol. 5, 1918, p. 244).